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Net Magnetic Force Generation in Discontinuous Circuits: A Force Symmetry-Breaking Phenomenon

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Abstract

This paper explores the potential for generating a net magnetic force in circuits with open sections, where the asymmetry of interacting forces can produce a resultant net force. It is shown that the forces between two wires can be decomposed into reciprocal and directional components. Reciprocal forces generally produce no net force, and directional forces vanish in closed circuits. However, directional forces may not vanish in discontinuous circuits. The central concept behind this work stems from a nuanced idea that may have been overlooked or remained unnoticed. The simplicity of the proposed idea could lead to the development of propulsion systems capable of repositioning satellites and heavy structures in Earth's orbit or even sending probes to neighboring solar systems within our lifetime.

This work originates from a thought experiment. Before diving into it, let's consider the famous example of two electrons moving perpendicular to each other, both approaching a common origin [1, 2]. Due to the Lorentz force and Biot-Savart law, these electrons will experience equal forces perpendicular to their velocities, though in distinct directions, seemingly violating Newton's third law.

Now, imagine two wire loops carrying currents. If we neglect the retardation effect[3], Newton's third law mandates that they must exert equal and opposite forces on each other. Can we design the loops' geometry and orientation to create a scenario similar to the electron experiment, where interaction forces act in different directions without canceling each other?

A strict physicist might immediately assert that this is impossible. Indeed, the mathematics presented in the Methods section proves that any two closed

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loops exert equal and opposite forces, resulting in overall cancellation. However, a question immediately arises: if two closed loops must produce equal and opposite forces, does removing part of a loop break this symmetry? As we will subsequently see, discontinuous circuits can indeed exhibit this force symmetry breaking.

In the study by Mohammadpour [3], it is argued that Newton's Third Law is only locally applicable at the point of interaction between fields and charges, where an instantaneous exchange of momentum occurs. It is deemed inappropriate to extend Newton's Third Law to interactions at a distance where retardation effects may occur and the state of the charges may change. Sebens [4] discusses since fields exert forces on charges and, conversely, charges exert forces on fields, Newton's Third Law is preserved. Without contradicting Newton's Third Law and using the Lorentz force as defined in equations (6) and (7), we can demonstrate that forces acting on two open wires might not always exhibit symmetry (Please refer to section Methods).

The accuracy of calculated forces using the Lorentz force is difficult to dispute. This is because the Lorentz force is deducible from Faraday's law of induction and Maxwell's equations using the Leibniz integral rule. Since Maxwell's equations offer an accurate description of fields for most classical electromagnetic applications, it's reasonable to consider the Lorentz force equally accurate when representing forces within the mentioned domain of application.

Methods

In the electrodynamic causality context, the magnetic field's exact solution around the wire from the Maxwell equation is presented in [5]. However, when neglecting the retardation effect and assuming a low rate of change in current, this description simplifies to the more familiar Biot-Savart law [1]

$$\mathbf{B} = \frac{\mu_0 I}{4\pi} \oint \left(\frac{d\mathbf{l}^s \times \mathbf{r}}{r^3} \right) \quad (1)$$

where μ_0 represents the permeability of vacuum and I denotes the current. Furthermore, $d\mathbf{l}^s$ represents an infinitesimal length element of the source, r is the distance from that source element, and \mathbf{r} is the displacement vector. The force exerted by wire A on wire B can be determined using the Lorentz force law

$$F_A^B = I_B \oint_B d\mathbf{l}^B \times \mathbf{B}_A \quad (2)$$

by converting the triple cross products to dot products, it follows

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\oint \oint \frac{d\mathbf{l}^A (d\mathbf{l}^B \cdot \hat{\mathbf{r}}_{BA})}{r^2} - \oint \oint \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (3)$$

where $\hat{\mathbf{r}} = \mathbf{r}/r$ represents the unit vector pointing from the infinitesimal element $d\mathbf{l}^A$ toward $d\mathbf{l}^B$, and r is the distance between these elements. The second term

on the right-hand side of Equation (3) implies equal and opposite forces on wires A and B. By expanding the differentials in spherical coordinates, it follows

$$d\mathbf{l}^B \cdot \hat{\mathbf{r}} = d\mathbf{r} \cdot \hat{\mathbf{r}} = dr \quad (4)$$

Using the identity (4), the force term (3) can be written as

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\oint_A d\mathbf{l}^A \oint_B \frac{dr}{r^2} - \oint \oint \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (5)$$

The closed integral $\oint \frac{dr}{r^2}$ equals zero for a closed wire. This is because the integration is performed over a closed loop on a function differential. Conclusively, two closed loops exert equal and opposite forces on each other. The second integral in Equation (5) can be named the "reciprocal force," possessing symmetry and is directionally dependent on both wires. In contrast, the first term in Equation (5) can be termed the "directional force," as its direction depends only on one of the wires and exhibits asymmetry. As previously stated, the directional force vanishes for a closed loop.

Now, consider two open-circuit wires. Each wire has a specific disconnection point, with a sufficiently small gap to act as a capacitor. Therefore, this configuration allows current to flow, dependent on the applied voltage and the charge accumulated at the disconnection points. Importantly, no discharge occurs between these disconnected points. Let's denote the disconnection points for wire A as O_A and O'_A and for wire B as O_B and O'_B (moving in the direction of the current). The interaction forces on wires A and B can be expressed as follows

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_A \left(\frac{1}{r_{O'_B}} - \frac{1}{r_{O_B}} \right) d\mathbf{l}^A - \int \int \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (6)$$

and

$$F_B^A = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_B \left(\frac{1}{r_{O'_A}} - \frac{1}{r_{O_A}} \right) d\mathbf{l}^B - \int \int \frac{\hat{\mathbf{r}}_{AB} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (7)$$

Here, r_O denotes the distance between point O and the infinitesimal element on the other wire. The reciprocal forces cancel each other. The net force between the two wires resulting from directional forces is then expressed as

$$F_A^B + F_B^A = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_A \left(\frac{1}{r_{O'_B}} - \frac{1}{r_{O_B}} \right) d\mathbf{l}^A + \int_B \left(\frac{1}{r_{O'_A}} - \frac{1}{r_{O_A}} \right) d\mathbf{l}^B \right] \quad (8)$$

It can be demonstrated that in many configurations, the net force between the open wires is non-zero. A clear illustration of this occurs when wire A and wire B lie in perpendicular planes, and the differential elements $d\mathbf{l}^A$ and $d\mathbf{l}^B$ are independent of each other.

Examples and discussions

Consider a scenario where alternating current (AC) passes through a primary circuit with two open sections. A dielectric material is placed within these openings, and the wire's cross-section is designed to function as a capacitor with no electrical discharge. The circuit voltage is sufficient to maintain the current flow in the primary circuit. Secondary circuits are positioned near the main circuit's open segments to produce a net force in the desired direction. Depending on the intended force direction, these secondary circuits can operate in-phase or out-of-phase with the primary circuit. System symmetries are designed to eliminate any potential net moment. Figure 1 provides a circuit schematic. The open section is denoted by O and O' . Secondary circuits are placed to the right and left of the primary circuit, near the open sections.

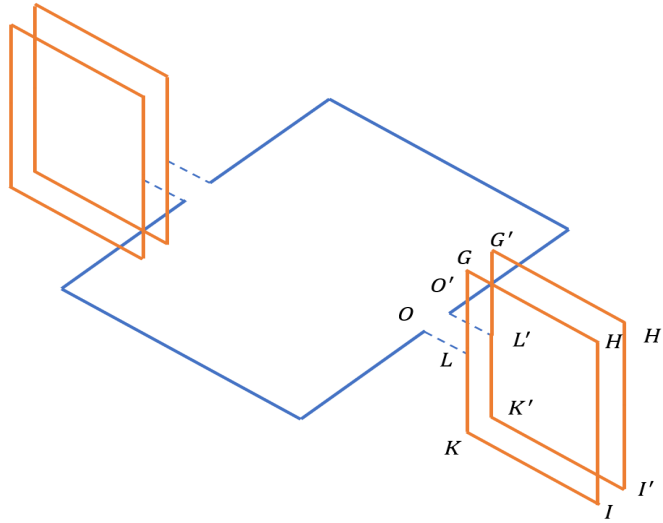


Figure 1: A simplified diagram of a novel AC-powered propulsion system. Open sections act as capacitors (using a dielectric material between points O and O'), while secondary circuits are positioned and phased for directional force generation. Secondary circuits are identical and symmetrical with respect to the main circuit plane (i.e., $GL = LK$).

The circuit design presented in Figure 1 aims to produce a net upward force. Segments GH and IK , as well as $G'H'$ and $I'K'$, negate each other's effects. KG and $K'G'$ contribute the most to the upward force, while HI and $H'I'$ have lesser contributions due to their distances, as outlined in equations (7) or (6). The AC in circuit $GHIK$ is out-of-phase with that of $G'H'I'K'$ to prevent force cancellation. The selection of AC is sinusoidal here. Therefore, the average force is half of the maximum force. There are no limitations on the number of open sections or turns in either the primary or secondary circuits, allowing for

scalable force generation. However, we'll consider a simple application here. A current of 1000 amps is used for both the primary and secondary circuits. The distance between O and O' varies, and GL and LK lengths are chosen 15cm each. To minimize counteracting force, HI is placed further away at a distance of 25cm . The secondary circuits are positioned opposite on each side to cancel out the moment produced in the main circuit and maintain symmetry. Figure 2(a) illustrates the average net force for varying distances between point L (in the secondary circuits) and the main circuit, ranging from 1cm to 20cm . Figure 2(b) illustrates the effect of distance between the gap OO' on produced average net force.

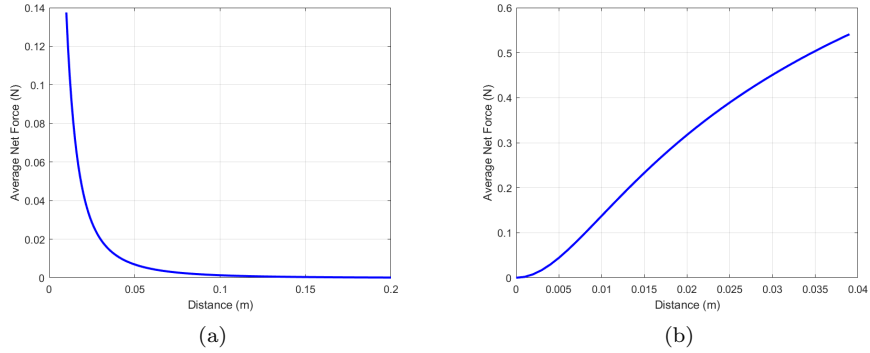


Figure 2: The average net force produced in the setup depicted in Figure 1, as a function of (a) the distance between secondary and main circuits (with a fixed $OO' = 1\text{cm}$) (b) the OO' distance (with a fixed initial distance of 1 cm between the main and secondary circuits).

To understand how discontinuous circuit sections can break force symmetry, consider the contribution of directional force (described by the first integral in Equation (3)) exerted by a unit length at the midpoint of line KG on a unit length along line NN' . This force is plotted for both continuous and discontinuous (with open sections) cases. Figure 3(a) illustrates the symmetry of directional forces in a continuous wire, leading to overall cancellation and no net force production. In contrast, Figure 3(b) demonstrates how open sections break this symmetry, resulting in a non-zero net force.

The power of proposed propulsion systems can be significantly enhanced by incorporating multiple turns and open sections. For example, using 20 turns and 20 sets of open sections instead of one can increase the forces depicted in Figure 2 by a factor of 400. For instance, we may potentially generate a force of approximately five kilogram-force by choosing a 1cm gap for the open sections and the distance between the secondary and the primary circuits. This force is sufficient to accelerate a probe with the mass of Voyager 1 such that it reaches the same distance traveled by Voyager 1 (up to January 2024) in less than a year. This cannot be achieved with traditional propellant-based propulsion systems,

as they require a vast amount of mass for constant acceleration.

Incorporating superconductors into this propulsion system could provide significant advantages and expand its potential applications to include terrestrial and aviation transportation. Unlike traditional electric motors, which lose energy through friction within their mechanical parts, this proposal eliminates such losses due to its lack of moving components. This characteristic paves the way for a highly efficient propulsion system.

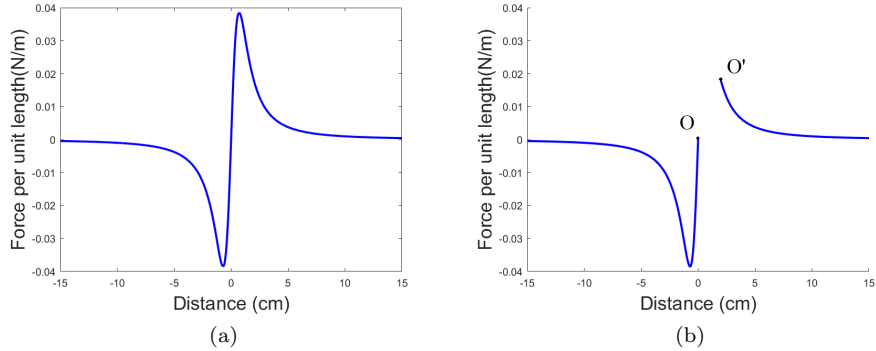


Figure 3: Directional force exerted by a unit length at the midpoint of line KG on a unit length along line NN' for two cases: (a) no open sections, and (b) a 2cm gap for the open section. The current in both main and secondary circuits is 1000 amps.

Conclusions

This research explored the breaking of symmetry in interaction forces of discontinuous circuits. It is demonstrated that in closed circuits, force interactions adhere to classical physics' expectations of reciprocity. Contrarily, this symmetry breaks in discontinuous circuits and can lead to a net resultant magnetic force. This claim aligns fully with the Lorentz force and Maxwell's equations, guaranteeing the conservation of momentum in field and charge interactions.

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This work is conducted without any external financial support. During the preparation of this work, the author has used several AI tools for grammar and readability enhancement, and no additional text has been generated by these tools. After using these tools, the author reviewed and edited the content as needed. Author takes full responsibility for the content of the publication

Call for collaboration

Ideas regarding this work are developed and patented. I extend an open invitation for collaboration and support to develop these concepts further to benefit the scientific community and humanity.

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